

IRRIGATION WATER MANAGEMENT
Training Manual No. 10

1928-0201 NSSI

IRRIGATION SCHEME OPERATION AND MAINTENANCE



Food
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Training Manual No. 10

IRRIGATION SCHEME OPERATION AND MAINTENANCE

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International Institute for Land Reclamation and Improvement

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 1996

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M-56
ISBN 92-5-103876-7

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Preface

This is one in a series of training manuals on subjects related to irrigation, started in 1985, that has raised a positive response among many practitioners of irrigation.

The papers are intended for use by field assistants and irrigation technicians at the village and district levels who want to increase their ability to deal with farm-level irrigation issues.

The papers contain material that is intended to provide support for irrigation training courses. Taken together, they do not present a complete course in themselves, but instructors may find them helpful when specific irrigation conditions are under discussion. The material may also be useful to individual students who want to review a particular subject without a teacher.

The series of documents prepared with ILRI includes the following ten subjects:

1. Introduction to irrigation
2. Topographic surveying
3. Crop water needs
4. Irrigation scheduling
5. Irrigation methods
6. Scheme irrigation water needs and supply
7. Canals
8. Structures for water control and distribution
9. Drainage of irrigated land
10. Irrigation scheme operation and maintenance.

The first edition of all the papers is provisional because experience with the preparation of irrigation material for use at the village level is limited. Once enough experience has been gained to evaluate the information and the methods outlined in the draft papers, revised versions can be issued.

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ABOUT THIS PAPER

IRRIGATION SCHEME OPERATION AND MAINTENANCE is the tenth in the series of training manuals on irrigation prepared jointly with ILRI (International Institute for Land Reclamation and Improvement). The manual presents some of the difficulties that irrigation organizations confront in undertaking their duties and provides some orientations on how to resolve them. The paper then proceeds to discuss the methods of operating an irrigation network and the working principles involved. The maintenance tasks are discussed. To draw similarities and differences the maintenance of a motorcycle is used as a reference for the corresponding activities in an irrigation scheme. Finally, a reference is made to the need for having an effective financial control whereby the management of the system has enough resources to undertake the operation and maintenance tasks. The manual is addressed to small and medium schemes and assumes that the management organization is already in place.

ACKNOWLEDGEMENTS

Much appreciation is expressed to the various specialists in irrigation for their valuable comments and contributions: Messrs M. Smith, J.A. Sagardoy and F. Chanduvi.

Acknowledgement is given to Mr Joop van Dijk who provided the drawings for this publication.

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Chapter 1

Introduction

Previous manuals have presented various techniques that are needed for irrigation:

- Topographic surveying.
- Determining crop water needs.
- Irrigation scheduling.
- Irrigation methods.
- Scheme irrigation water needs and supply.

Two other manuals have described essential parts of an irrigation scheme:

- Canals.
- Structures.

This manual explains what it takes to make an irrigation scheme function, and how to keep it functioning.

The first thing needed in an irrigation scheme is people, people working together. This is the topic of Chapter 2, **Organization**. This chapter explains why an irrigation scheme is more difficult to manage than other types of organizations. The ways of coping with those difficulties are then explained.

In Chapter 3, **Operation**, the management of the central task in an irrigation scheme, which is to supply irrigation water, is discussed. Chapter 4, **Maintenance**, is about the efforts that have to be made to keep the scheme in good working order. Finally, Chapter 5, **Financial Control**, explains how to find the money to pay for all these activities.

NOTE:

1. This manual mostly addresses operation and maintenance of **small- and medium-sized** irrigation schemes.
2. The manual assumes that an organization for scheme operation and maintenance is already in place; it therefore does not provide guidelines on the establishment of such organizations or of water users' associations.

Chapter 2

Organization

WHAT MAKES IRRIGATION MANAGEMENT DIFFICULT?

An irrigation scheme supplies irrigation water to farmers, so they can obtain higher yields than they could without irrigation.

This is not so very different from, for example, a fertilizer company, which supplies fertilizer so that farmers can obtain higher yields than they could without fertilizer.

QUESTION: Since both activities seem more or less the same, why should an irrigation scheme be so much more difficult to manage than a fertilizer company?

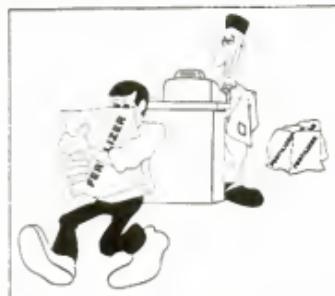
Before turning the page, list as many answers as you can think of.

ANSWER: Compare your list of answers with those below. Has anything been forgotten?

An irrigation scheme is more difficult to manage than, for example, a fertilizer company, because:

- **It often involves two different organizations** (Figure 1). The fertilizer company sells to individual farmers, whereas an irrigation scheme often supplies water to a group of farmers, who then have to distribute the water to individual members of the group. This means that managing an irrigation scheme may involve two different organizations: one for managing the supply of water to the groups, and another for distributing water within each group.
- **It involves more complicated operations** (Figure 2). Both irrigation water and fertilizer have to be applied in accordance with the requirements of the crops. With fertilizer, it is the farmer who makes all the decisions on when to apply it, and how much to apply. The managers of an irrigation scheme first have to obtain information on the farmers' water requirements, then draw up a delivery schedule, adjust the gate settings throughout the scheme, make the deliveries, and then start all over again for the next round of applications!
- **There is more likelihood of conflicts** (Figure 3). Far more, in fact:
 - * conflicts among farmers within a group of water users;
 - * conflicts among groups of water users;
 - * conflicts among the groups and the managers of the main system.

FIGURE 1
Irrigation often involves two organizations

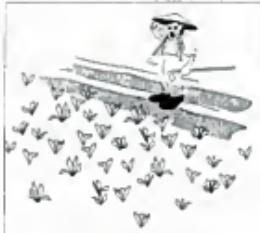


Fertilizers are delivered to one customer at a time



Irrigation deliveries are often shared by many users

FIGURE 2
Irrigation operations are more complex



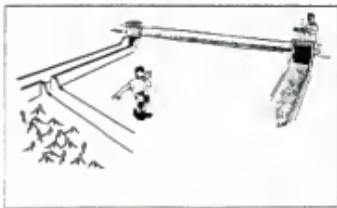
a farmer sees that the crops need fertilizer



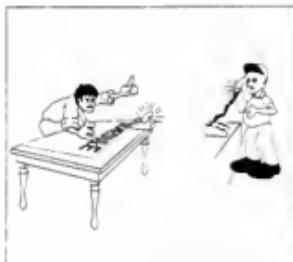
a farmer solves the fertilizer needs of the crops



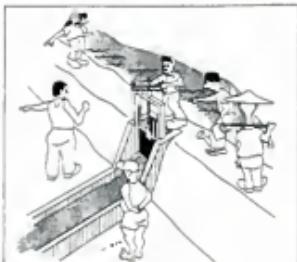
a farmer sees that the crop needs water



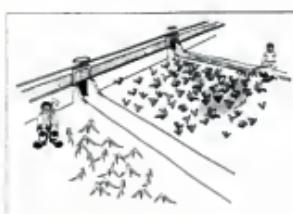
a farmer tries to get the attention of the operator



the operator telephones the engineer who prepares the delivery schedule



the operator adjusts the turnout



the farmer has to wait for his turn



finally the farmer can apply water to his crops

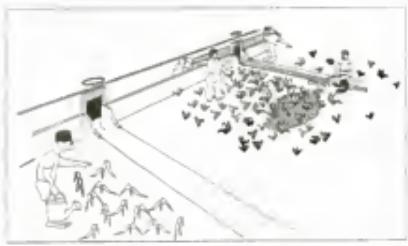
FIGURE 3
Irrigation creates more conflicts



farmer confronts shopkeeper with a hole in a fertilizer bag



confrontation between two farmers in the same unit



confrontation between farmers of more than one unit



confrontation between a group of farmers and the operator

- Such conflicts are more difficult to solve (Figure 4). With fertilizers, the farmers know exactly how much they have received. When in doubt, they can always check the amount. If the farmers are not satisfied with the services of a particular supplier, they can go to another supplier!
- Obtaining payment from the farmers is more difficult (Figure 5). If farmers do not pay, the fertilizer company simply stops supplying them. It is much more difficult to stop water deliveries to one farmer when water is delivered to a group. While it is technically possible to close off a whole group, this is not attractive for the irrigation scheme managers. Unlike the fertilizer company, they cannot sell their supplies to other customers outside the irrigation scheme!
- Irrigation demand may exceed supply (Figure 6). If a fertilizer store runs out of supply in periods of high demand, the storekeeper just orders more bags from the company. In an irrigation scheme, the maximum supply is limited by water availability and canal capacities. This is another source of conflicts!

From the above, the different nature of an irrigation scheme and a fertilizer company becomes apparent. Deals between a fertilizer company and a farmer are deals between two private-entities, which are regulated by market rules. In irrigation schemes, the organization that distributes the water is often of a public nature, while the group of farmers receiving the water is often again a private institution. This mix of public and private institutions who all have their different rules makes irrigation management especially difficult!

Not all irrigation schemes have this mixed type of management. Two other types exist:

1. Public-managed schemes;
2. Farmer-managed schemes.

In **public-managed** schemes, a single government agency is responsible for water management and for agricultural management. As all decisions about cropping schedules and water deliveries are made by the same agency, there are fewer conflicts. The disadvantage is that any management mistakes will also lead to failure on a large scale! The position of farmers in a public-managed scheme is more similar to that of workers in a factory.

In **farmer-managed** schemes, all decisions on irrigation and agricultural issues are made by farmers. The irrigation issues above the farm level, such as main system operation and maintenance are performed by farmers operating as a group. Irrigation and agricultural issues at the farm are decided by the individual farmer.

HOW TO COPE WITH DIFFICULTIES IN IRRIGATION MANAGEMENT?

Managing an irrigation scheme often involves two different organizations:

- the scheme operators, who manage the water from the main intake structure to each of the outlets shared by a group of farmers;
- the farmers who share a common outlet.

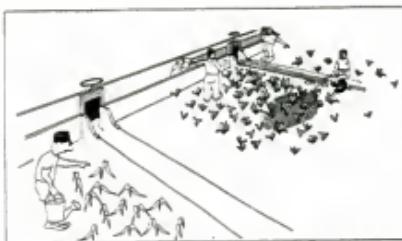
FIGURE 4
Conflicts in irrigation are more difficult to solve



the fertilizer bag is repaired and the bag
refilled to the correct weight



confrontation between two farmers in the same unit continues



confrontation between farmers of more than one unit continues



confrontation between a group of farmers and the operator
continues

FIGURE 5
With irrigation it is more difficult to obtain payment from farmers

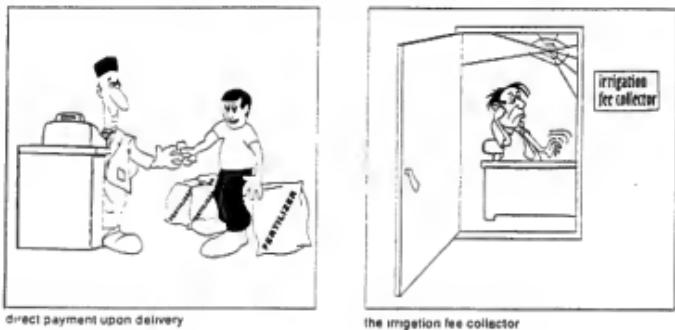
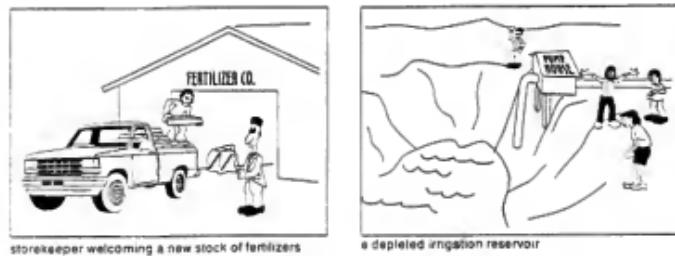


FIGURE 6
It is often not possible to meet irrigation demand



If the scheme operators depend, wholly or partially, on financing by the government, there is even a third party involved: the government.

These three parties do not always want the same things! Let us look at what each party expects from an irrigation scheme.

Farmers' objectives. Farmers expect an irrigation scheme to help them produce greater yields. To obtain maximum yields, the farmers would like to have immediate access to irrigation water, and to have total freedom to take irrigation water whenever they need it, at a rate that suits them best, and for as long as they want.

Freedom in timing allows farmers to irrigate when it best suits them and their crops. Freedom in choosing the rate of water supply helps to distribute the irrigation water more uniformly. Freedom in choosing the duration of the water supply will help the farmers to continue irrigation for as long as is needed to restore soil moisture. This prevents them from applying too much or too little irrigation water.

Government objectives. Just like the farmer, the government expects the irrigation scheme to increase crop production. The government, however, is also concerned with creating employment and reducing rural poverty. The government therefore prefers to spread the benefits of irrigation over a large group of people. Irrigation schemes cost money to construct, operate and maintain. Irrigation also requires a lot of water. Spreading the benefits of irrigation over a large group of farmers means that there is usually not enough money and water available to give every farmer immediate access to irrigation water and total freedom in the timing, rate and duration of water supply. As a result, farmers in most irrigation schemes have to share an outlet with other farmers and are not free to take water as they would like to do.

Scheme operators' objectives. The scheme operators are caught in the middle: the farmers expect them to provide irrigation services that are adequate to increase crop production, while the government wants them to serve a large group of people at the lowest possible cost to the government. The scheme operators' objective is to manage the scheme in a way that is acceptable to all parties.

QUESTION: How can a situation acceptable to all be created?

ANSWER: A service agreement is needed, which specifies:

- the irrigation services that the scheme operators will provide to the farmers;
- what the farmer has to contribute - in cash, labour or otherwise - in return for the irrigation services;
- the methods used to check whether the services are provided and whether the farmers' contributions are made, as was agreed upon;
- the action that will be taken if any party falls short of fulfilling the agreed-upon obligations.

NOTE: The service agreement is mostly applicable to schemes with a mixed (public-farmers) management. In farmer-managed schemes, it can be used to describe the arrangements between the individual farmer and the group of farmers who together act as scheme operators.

Two important types of irrigation services that the scheme operators are capable of providing are:

- Water deliveries. These will be discussed in Chapter 3, Operation;
- Maintenance services. These will be discussed in Chapter 4, Maintenance.

The farmers' contributions in return for the irrigation services, and the methods used for financial control, will be discussed in Chapter 5, Financial Control.

The remainder of this chapter discusses:

- the role of water users' associations;
- how to prepare a service agreement;
- the need for adjustments and improvements.

THE ROLE OF WATER USERS' ASSOCIATIONS

Developing, operating and maintaining an irrigation scheme almost always requires joint action by the water users. In traditional irrigation schemes, farmers would get together to build a diversion weir across a river or dig an access canal, because these were things they could not accomplish on their own. Without a capacity for organization and decision making among the users, it was simply not possible to complete a scheme. This capacity helped users to develop an organization capable of operating and maintaining the scheme.

In a modern scheme where most of the preparation and construction is done by a government agency, the water users have much less experience in organizing themselves. Yet the fact that in such schemes the water is usually delivered to a group of farmers requires a water users' association (WUA) that is capable of assuming responsibility for water distribution among farmers. In many cases, the WUAs are also responsible for maintenance and for collecting irrigation fees from its users. WUAs could also play an important role in negotiating with the scheme operators on the service agreement.

HOW IS A SERVICE AGREEMENT PREPARED?

The service agreement is between two parties: the farmers (or their WUAs) and the scheme operators¹. In the section *How to cope with difficulties in irrigation management*, these two parties can have different objectives. This means that when the service agreement is being drawn up, the two parties have to negotiate with one another. This manual does not provide guidelines for conducting such negotiations. It is believed that farmers and scheme operators need to develop their own methods and skills, so that these are well suited to their culture and customs. The issues that could be taken into consideration are discussed below.

¹ An example of such an agreement is given in Annex 1, covering the procedure for requesting and delivering water. Similar agreements can be drawn for maintenance or any other service as needed.

Small-scale schemes

In small-scale schemes, the negotiations could probably be conducted in a series of meetings attended by all the farmers and all the scheme operators. But since it is not always possible for every farmer to attend every meeting, the farmers' group must agree on the number of farmers who need to be present to make the decisions of the meeting binding for the whole group.

Another important issue is the participation of women in these discussions. In many irrigation schemes, women are very active in irrigated agriculture; this means that they also need to be involved in drawing up the service agreement.

Even in small schemes, different farmers can have different interests, and for many different reasons. To mention a few:

- A farmer may be rich or poor: A rich farmer can more easily obtain inputs such as credit, seeds, and fertilizers, so that even on the same area of land he/she can benefit more from the irrigation scheme than a poor farmer can.
- The farm may be large or small: On a large farm, it is usually easier for the farmer to store irrigation water and to use it whenever it is convenient.
- The farm may be at the head-end of the scheme or at the tail-end of it: Head-enders usually find ways of obtaining more water from the scheme than tail-enders.

A rich farmer with a large farm located at the head-end of the scheme is likely to propose another type of service agreement than a poor farmer with a small piece of land at the tail-end of the scheme. In the negotiation process between the farmers and scheme operators, the voices of the richer, larger and head-end farmers are likely to be louder than those of the poorer, smaller and tail-end farmers. A service agreement based only on the loud voices may well result in a situation where the less privileged farmers will not benefit enough from the scheme to be able and/or willing to contribute to its operation and maintenance.

On the other hand, if a service agreement is over-protective of the less privileged and less productive farmers, it may be difficult to obtain the contributions that the farmers need to make for the continued operation of the scheme.

Medium- and large-scale schemes

In medium- and large-scale schemes, the larger number of farmers involved makes it more difficult to conduct negotiations with all the farmers. One option would be to conduct separate meetings for each group of farmers that share a common outlet. This option, however, would result in different service agreements for different parts of the scheme. There are certain advantages of having a uniform agreement for the whole scheme:

- For the scheme operators, it is more practical - technically and administratively.
- For the farmers located at the tail-end of the scheme, it guarantees them the same level of service as the other groups.

- For both farmers and scheme operators, it makes it possible to arrange for farmers to assume responsibility for operating and maintaining part of the scheme above the level of their outlet.

In negotiating such a uniform service agreement, each group participates through a number of representatives chosen by the group. It is important that these representatives are chosen on the basis of their ability to represent the common interests of the group; they should preferably not be the richest, most powerful or largest farmers. As discussed above, such farmers may have interests that differ from those of the majority of farmers in the group. Other important points are that the representatives should inform the other members of the group about what is going on in the negotiations, and that, before important issues are decided upon in the negotiations, a consensus is obtained within the group.

NEED FOR ADJUSTMENT AND IMPROVEMENT

The service agreement is the result of negotiations between parties whose objectives may differ. One cannot expect that the first service agreement will be perfect. Experience during the first irrigation season will show:

- Whether the irrigation services could be provided according to the agreement, or whether this did not always happen.
- Whether the scheme operators took appropriate corrective action.
- Whether the farmers made their contributions in return for the services.

Even with positive experience on the above items, the following questions still need to be asked:

- Whether the irrigation services as provided according to the agreement were adequate for crop production, or whether they could be improved.
- Whether the farmers' contributions were adequate to cover the costs of operating and maintaining the scheme.

These types of questions need to be asked after every irrigation season and, if necessary, the service agreement should be adapted accordingly. This means that the organizational arrangements made to produce the service agreement need to remain in place permanently, to ensure that the scheme is capable of adjustment and improvement.

Chapter 3

Operation

The most important service that the scheme operators provide to farmers is the delivery of irrigation water.

Ideal from a farmer's point of view is freedom in terms of:

- *timing*,
- *flow-rate*, and
- *duration* of irrigation applications.

Figure 7 shows a design which allows every farmer to take as much irrigation water as he/she wants, at any time, for as long as he/she wants. The design of this irrigation scheme resembles that of a drinking water supply system. The major difference is the required capacity of the outlet valve.

FIGURE 7
Underground pipe with risers and valves serving ten farms

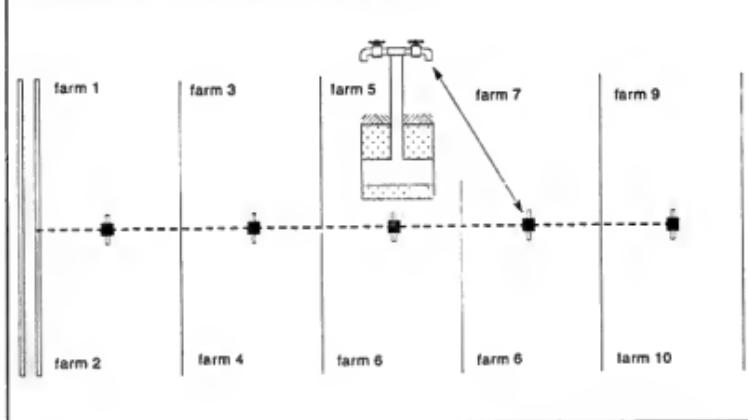
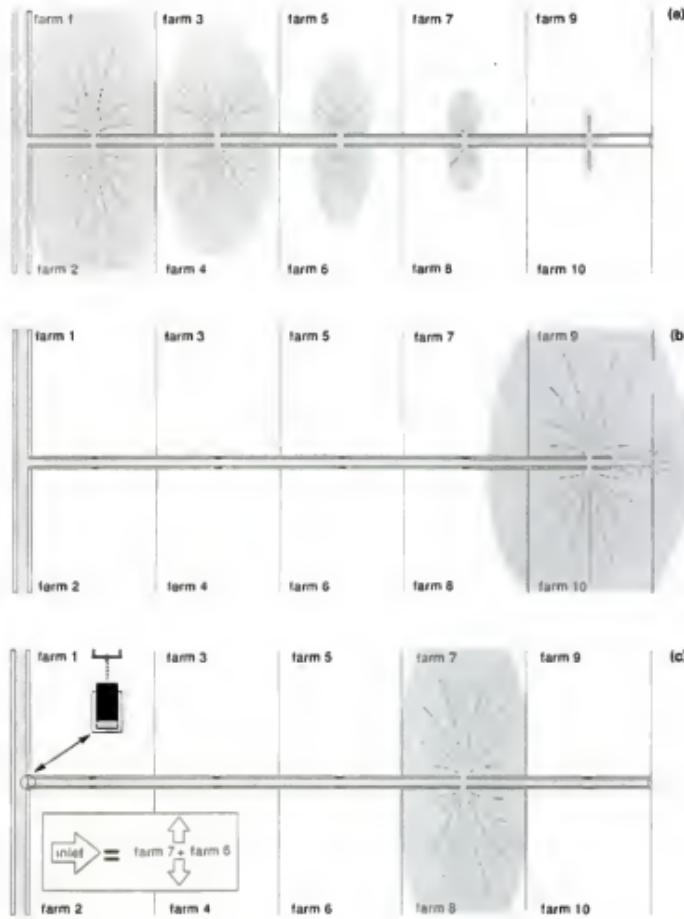


FIGURE 8

An open canal serving ten farms: (a) Too many farmers located upstream in the scheme are irrigating so that farmers downstream receive no water. (b) If farmers suddenly stop irrigating, the canal will overtop. (c) In an open canal scheme, the flow size entering the scheme must equal the sum of the flow rates delivered to farmers.



Example: To supply a field of 1 hectare with 50 mm of irrigation water in 8 hours needs a flow rate of:

$$\frac{100 \text{ m} \times 100 \text{ m} \times 0.05 \text{ m}}{8 \times 60 \times 60 \text{ sec}} = 0.0174 \text{ m}^3/\text{s} = 17.4 \text{ l/s}$$

This is almost 50 times the capacity of the larger taps in a house! The cost of such an irrigation outlet valve is about 25 times the cost of the household tap!

Conclusion: Because irrigation requires large flow rates, designs based on closed conduits and valve outlets are often considered too expensive. As a result, there are more irrigation schemes with open canals than with closed pipe systems. Figure 8 represents such an open canal scheme.

Farmers in an irrigation scheme of this type cannot just open and close their gates as they wish. If too many farmers who are located closer to the source are irrigating, the downstream users will receive no water (Figure 8a). If farmers stop irrigating, the canal will overtop (Figure 8b).

Conclusion: In an open canal scheme, the flow entering the scheme must equal the sum of the flows delivered to the farms (Figure 8c).

How easy, or how difficult, it is for the scheme operators to fulfill this condition depends on which method of water distribution has been selected in the design of the scheme.

What are the methods for water distribution in an open canal scheme? Suppose there is a canal that provides irrigation water to ten farms of equal size (Figure 8). The maximum discharge of the canal is 60 l/s.

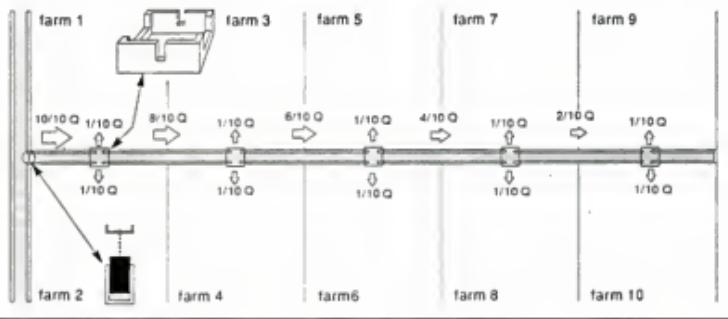
One method of water distribution is **flow sharing or proportional delivery**; every farm receives an equal share of the canal discharge. In the example given here (Figure 9), this provides each farmer with a maximum flow of 6 l/s. The structure that is suitable for this method of water distribution is the proportional division box. The flow over each weir is proportional to the width of the crest, provided that these crests have the same height and shape. This method of water distribution does not need any action by farmers or operators for regulating the flow of irrigation water to the farms.

Another method is **time sharing or rotation**; every farm in turn receives the full canal discharge. In the example, this would provide each farmer with a maximum discharge of 60 l/s. The duration of an irrigation delivery to one farm must be chosen in a way that both meets the irrigation water needs of the crops and is convenient to the farmers. With this method, there is no need for a flow division structure. It may be convenient to have structures which allow either closure or passage of the full canal flow (Figure 10). The method does require action from operators or farmers to direct the canal flow to the farm that is scheduled to receive irrigation water.

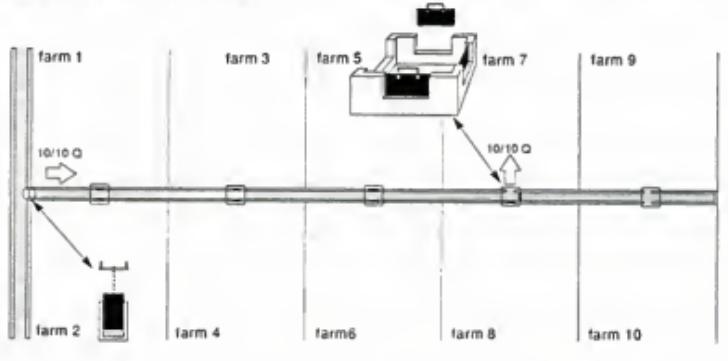
FIGURE 9

Flow sharing or proportional division of a flow of 60 l/s among ten farms by means of proportional division boxes

NOTE: The flow over each weir is proportional to the width of the crest, which have the same height and shape.

**FIGURE 10**

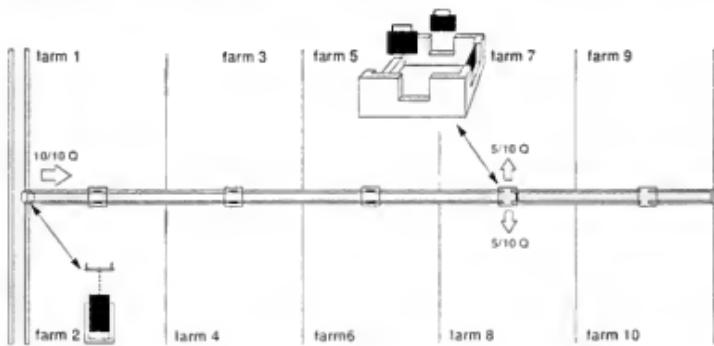
Time sharing or rotation of a flow of 60 l/s in a group of ten farms using gated structures which are either fully open or fully closed



A third method is a combination of time sharing and flow sharing. Instead of supplying the full flow to one farm, the flow of 60 l/s could be divided into two equal flows of 30 l/s which are delivered to two farms simultaneously. This can be accomplished with a division box with openings of the same size (Figure 11). This method also requires action from operators or farmers; at the end of irrigation delivery to one pair of farms, the canal flow must be directed to the next pair.

FIGURE 11

Rotational delivery to a group of ten farms with flow sharing between two farmers at a time by means of gated division boxes with openings of the same size



Question: For a group of 10 farms which need to share a maximum flow of 60 l/s, which of the three above methods would you recommend?

Answer: With **flow sharing or proportional distribution**, each farm would receive 6 l/s. This is about half a bucket of water each second. A skilled irrigator could handle more than this.

With **time sharing or rotational irrigation**, each farm receives in turn the full flow of 60 l/s, or about five buckets of water each second. Especially on erosive soils, this could be more than even a skilled irrigator can handle.

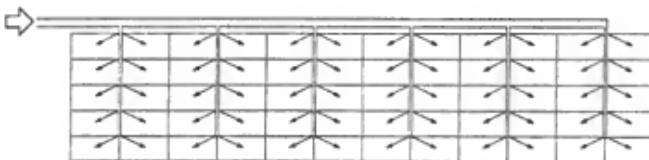
The third method provides the farm with 30 l/s in turn. This is about two or three buckets of water each second, which is a flow that most irrigators can conveniently handle. For the above example, therefore, the third method is recommended.

METHODS FOR WATER DISTRIBUTION TO TERTIARY UNITS

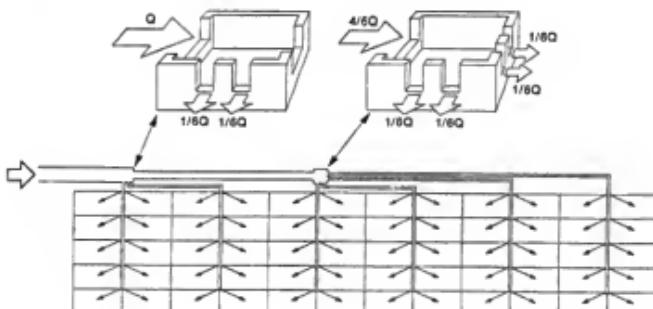
The design shown in Figure 7 is based on a closed pipe system and every farm is provided with its own outlet valve. This design resembles a drinking water supply system with a tap in each house. It has been noted that due to the large flows needed in irrigation, such designs are mostly too expensive. In order to reduce costs, irrigation schemes more often use open canals. A further cost reduction is obtained by letting a group of farmers share a common outlet.

FIGURE 12

Layout of an irrigation scheme that provides water to 60 farms grouped into six tertiary units of ten farms each

**FIGURE 13**

Proportional distribution



NOTE: The same cost-saving practice of sharing a common outlet is used in the drinking water supply sector. Especially in rural water supply systems and in systems serving the urban poor, one tap is often shared by a hundred people and more. Such a design offers a lower level of service to the individual user, but the cost per user is also very much lower than for a system that provides an individual tap to each household.

In addition to reducing costs when building the scheme, sharing a common outlet by a group of farmers also reduces the operational tasks of the scheme operators. Figure 12 presents a layout of an irrigation scheme that provides water to 60 farms. By grouping these

60 farms into six tertiary units of ten farms each, the operators need to look after six outlets only.

In the following sections, four different methods of water distribution to the six tertiary units in Figure 12 are discussed. These methods are:

- proportional distribution;
- upstream control with vertical gates;
- upstream control with weirs;
- downstream control.

For each method, the working principles and required structures will be described, together with the major implications of the method for users and operators, and for the irrigation efficiency. Within the tertiary units, water is distributed as in Figure 11; the full flow from the offtake is shared by two farms at a time.

Proportional distribution (Figure 13)

Working principle: With proportional distribution, each tertiary unit receives an equal share of the discharge available in the canal.

Structures: The flow is divided by means of weirs. The weirs within one structure all have the same height and shape. The flow over the weir is proportional to the width of the crest.

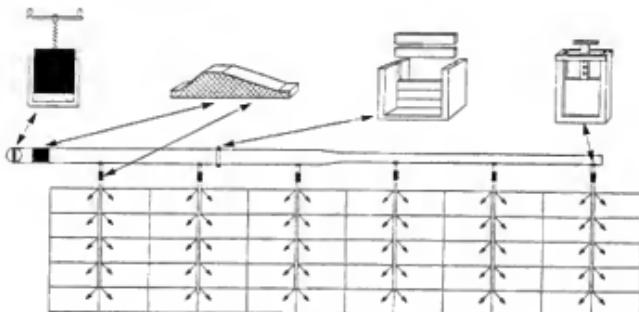
NOTE: In the design of Figure 13, the offtakes for two tertiary units are combined in one structure. This is for two reasons: (i) cost-reduction, by reducing the number of structures, and (ii) at each structure, the upstream water level needs to be at least 5 to 10 cm higher than the downstream water level. Putting in more structures would have required a higher water level in the upstream canal section.

Implications for operators: The offtakes in this design are fixed and require no intervention from scheme operators. At least once in every irrigation season, the weirs must be inspected and, in the case of irregularities, be repaired.

Implications for users: The design provides an even share of the available water to each farm in the scheme. This water arrives at each farm, irrespective of the cropping pattern and the irrigation water requirements. It is entirely up to the farmers how to make the best possible use of the water.

Implications for irrigation efficiency: The main objective of this design is even distribution of the available water and not irrigation efficiency. If the available flow per unit of land is low and farmers still manage to grow a crop, the irrigation efficiency could be high. In all other cases, the irrigation efficiency is low. This is because water continues to be distributed, even when it is not needed. In order to improve water use efficiency, the scheme could be provided with a gate or stoplogs at the entrance of the main canal. This gate can be gradually closed, according to the irrigation water requirements in the scheme. A further improvement

FIGURE 14
Upstream control with vertical gates



of irrigation efficiency might be obtained by providing the tertiary offtakes with a flashboard. This would allow conveyance of water to only those tertiary units that need to be irrigated.

NOTE: With such flashboards, the distribution of the irrigation water is no longer proportional. Under these conditions, the functioning of the scheme resembles that of the schemes discussed in the following sections.

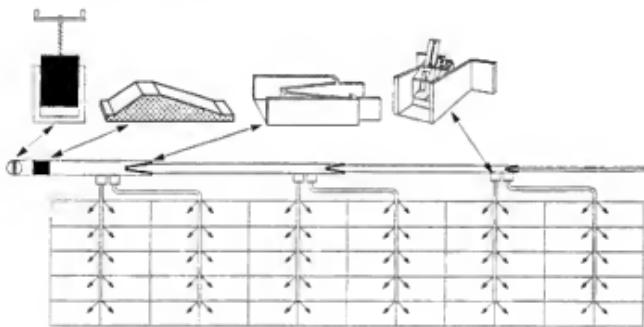
Upstream control with vertical gates (Figure 14)

Working principle: The discharge at each tertiary offtake is regulated with a vertical slide gate, according to the irrigation water requirement of that tertiary unit. A gate at the head of the canal allows adjustment of the flow size entering the scheme to the sum of the flow rates delivered through the tertiary offtakes. Check structures along the main canal maintain sufficient water depth at the offtakes when the canal is operated at lower than design capacity.

Structures: The offtakes are vertical slide gates. In the example, the maximum discharge of each offtake is limited to 60 l/s. Such a small discharge requires a small gate only, which can be operated directly by hand. The offtake gate in Figure 14 can be locked in the required position with a pin. Larger capacity offtakes would have to be operated with a handwheel. Immediately downstream of the offtake gate there is a measuring flume.

NOTE: It is recommended to use long-throated measuring flumes. Unlike for Parshall flumes or cut-throat flumes, a rating table can be calculated for long-throated flumes with an error of less than 2% in the listed discharge.

FIGURE 15
Upstream control with duckbill weirs



At the head of the main canal, there is a slide gate and measuring flume with a capacity equal to the design capacity of the main canal (360 l/s). This gate is operated with a handwheel. The check structures in this example are provided with stoplogs. In larger schemes, the check structures may be equipped with handwheel operated vertical slide gates.

Implications for operators: The correct operation of this design is very demanding on the operators. They need to collect information on the irrigation requirements of each tertiary unit, draw up a delivery schedule, and set the gates at the head of the canal and at each offtake according to the schedule. The last task is especially difficult: the discharge through an offtake depends on the opening of the gate and the water level in the main canal, which in turn is influenced by the discharge through that offtake. This means that the operator will have to adjust the gate opening at each offtake several times in order to achieve the discharge as specified in the delivery schedule. When operating the scheme at lower than design capacity, the operators need to put in stoplogs at the check structures in order to obtain sufficient water level at the offtakes.

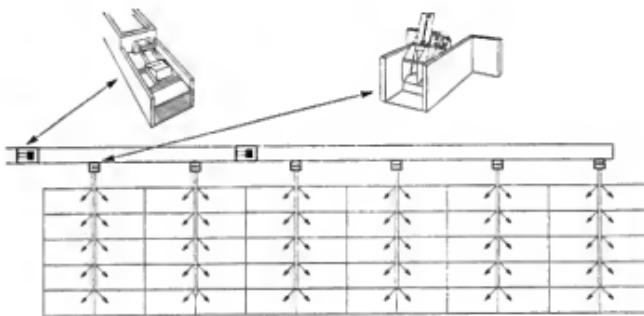
Implications for users: This design has the potential of providing tertiary units according to their irrigation requirements. The correct functioning of the scheme depends very much on the skills and dedication of the operators and requires good communications among users and operators.

Implications on irrigation efficiency: It is only possible to achieve a high irrigation efficiency if the above conditions for correct functioning of the scheme are met.

Upstream control with duckbill weirs (Figure 15)

Working principle: This design also allows water delivery according to tertiary units according to their water requirements. It is easier to operate than the design described in the previous section. The simpler operation is achieved by:

FIGURE 16
Downstream control



- maintaining a nearly constant water level at the offtakes, by means of duckbill weirs;
- replacing the vertical slide gate at the offtakes with constant discharge distributors that can be set at any value between 0 and 60 l/s that is a multiple of 5 l/s.

With this arrangement, the offtakes can be set to the required discharge in one operation, without the need for flow measurement and readjustment of the offtakes.

Structures: The duckbill weirs are located just downstream of the offtakes. In order to reduce the number of structures, the offtakes are grouped in pairs. Due to the long horizontal crest of the duckbill weirs, the variation in water level with canal discharges between zero and full design capacity is less than 10 cm. Each offtake is provided with a set of 4 distributors that provide a constant discharge of 5, 10, 15 and 30 l/s when fully opened. The design and operation of the gate and measuring flume at the head of the main canal are the same as in the previous section.

Implications for operators: This design also requires drawing up of a delivery schedule, as in the previous design. Due to the duckbill weirs and the constant discharge distributors, however, the setting of the offtakes to the required discharge is much easier than with the design that is described in the previous section. The duckbill weirs are made from concrete and have no moving parts. The constant discharge distributors, however, do have moving parts and are made from steel or fibre glass. They are treated with special paints to protect them from corrosion. This calls for frequent inspection and immediate repair of damage to the painted surface.

Implications for users: Like the previous design, this design is capable of providing irrigation water to each tertiary unit according to its requirement. Due to its easier operation it is more reliable than the previous scheme, provided that the distributors are well maintained.

Implications on irrigation efficiency: The design permits the achievement of a high irrigation efficiency.

Downstream control (Figure 16)

Working principle: This design allows the discharge at any of the offtakes to be changed at any time. By using gates that keep a constant downstream water level, the inflow into the main canal responds automatically to such a change.

Structures: The offtakes are similar to those used in the previous section. There are two constant downstream level gates, one at the head of each section of the main canal. Whenever one or more shutter gates of the distributors at the offtakes 3, 4, 5 or 6 are opened, the water level in the second section of the main canal goes down. The float of the second automatic gate goes down and the gate leaf goes up, thereby increasing the discharge into the second canal section. As more water is released from the first to the second section, the water level in the first section also goes down. This in turn leads to an increase of the opening of the gate at the entrance of the scheme. Figure 16 explains the working principle of a constant downstream level gate.

Implications for operators: This design requires no setting of gates by the operators. There is also no need for operators to draw up a water delivery schedule for the whole scheme, because tertiary units are free to change their gate settings whenever they want. Operators need to check frequently on the proper operation of the automatic gates and need to inspect gates and distributors for damage and repair them without delay. They also need to inspect the canal for leakage (for reasons discussed below under irrigation efficiency).

Implications for users: Users are free to set their offtake to the requirement of their tertiary unit, without a need to communicate with the operators of the scheme.

Implications on irrigation efficiency: When functioning properly, irrigation efficiency can be high because only as much water enters the scheme as is desired by the users. This no longer holds when users waste water at the farm. Another problem occurs when there is leakage from the canal. The automatic gates will treat leakage in the same way as an increase in irrigation demand. If such leakage is allowed to continue, the irrigation efficiency will be reduced.

NOTE: Downstream control is normally associated with irrigation schemes of a relatively high standard of design and mostly managed by government institutions. The design is included here with the purpose of demonstrating that freedom in terms of timing, flow rate and duration of irrigation applications at the head of the tertiary unit is technically feasible.

IRRIGATION PLANNING AND SCHEDULING

Irrigation planning

Irrigation planning involves making decisions on the cropping pattern for the coming irrigation season. In some schemes, irrigation planning is done by the managers of the scheme. In those schemes, farmers grow crops that are prescribed by the scheme managers. Preference, however, is to consider the farmer as the person who is responsible for running his or her own business. This includes making decisions on what crops to grow.

In deciding on what crops to grow in the next season, the farmer will consider:

- crops that meet the farming family's basic food requirements;
- crops that can be sold in the market at a profit.

The cultivation of each of these crops will require a different set of inputs such as seed, fertilizer, labour and irrigation water. The farmer must be confident that all of these inputs will be available in sufficient quantity to grow all of the selected crops in a satisfactory manner. For inputs such as seeds and fertilizer, the farmer can check with one or more suppliers. For labour inputs, the farmer will use his or her own experience to judge whether the labour resources at disposal are adequate to do the land preparation, planting, weeding, irrigation, plant protection, harvesting, transporatation and threshing for all of the selected crops. For crops that he or she has no previous experience with, the farmer can ask other farmers or an agricultural extension agent for advice.

For the input of irrigation water, however, it is more difficult for the farmers to check by themselves whether this input will be available at the right time and in sufficient quantities to support the crops of their choice. It is more difficult, because:

- the farmer does not know the total water needs of the scheme and the total water resources available to the scheme;
- the farmer does not control the allocation and distribution of irrigation water in the scheme.

When farmers are absolutely free to select their own cropping pattern, a situation may develop during the irrigation season in which the water resources available to the scheme are no longer adequate to meet the irrigation needs of the farmers in the scheme. This risk can be reduced if farmers submit their cropping plan to the scheme operators before the start of the irrigation season. By using the methods explained in Training Manual No. 3 (Irrigation Water Needs) and No. 6 (Scheme Irrigation Water Needs and Supply), the scheme operators could check if the *expected* water resources available to the scheme are adequate to meet the *expected* irrigation needs.

Note: Both water resources and irrigation needs during the irrigation season can be different from what was expected in the case of abnormal weather conditions.

If water resources are adequate, then shortage of water is not a reason for restricting farmers' freedom in selecting their own cropping pattern.

If water resources are not adequate, this is one reason for imposing some restrictions. Other reasons for limiting the individual farmer's freedom of choice are:

- Drainage problems; if one farmer grows rice and wants to maintain a water depth of some 0.1 m on top of the fields, the water leaking from these fields may create problems in neighbouring farms that are planted with crops that require a well-drained soil.
- Water delivery problems; in designs that use division of flow within the tertiary unit, it is difficult to adapt water deliveries to irrigation requirements of individual farms.

To avoid these problems in schemes where farms are grouped into tertiary units, it is recommended that farmers within each tertiary unit get together for drawing up their cropping pattern for the next irrigation season. As a general rule, they should try to avoid the combination of rice and non-rice crops in one tertiary unit. If this is not acceptable to the farmers, they could consider concentrating rice cultivation in one part of the tertiary unit. This part needs to be chosen in such a way that the water management activities for the rice crop cause minimal problems to the other crops.

After farmers have drawn up the cropping pattern for their tertiary unit, they submit it to the scheme management. From the cropping pattern of each tertiary unit, the scheme management calculates the expected irrigation needs for each tertiary unit and for the total scheme, using the methods described in Manuals 3 and 6. The cropping patterns are acceptable if, at any time during the coming irrigation season:

- the expected operational irrigation need for each tertiary unit does not exceed the discharge that can be delivered from the offtake;
- the expected operational need for the scheme¹ does not exceed the available scheme water supply².

In order to match irrigation needs with irrigation supply, the scheme managers may propose a number of strategies. They could advise to:

- set a maximum for the area that can be cultivated with crops that have a high irrigation need, such as rice or sugar cane: for example, not more than 50% of the area in each tertiary unit may be planted with rice;
- stagger the growing season within each tertiary unit, in order to reduce its peak water requirement;
- concentrate the planting period within each tertiary unit and stagger planting periods at scheme level; in this way the peak water requirements of the tertiary units will occur one after another, instead of simultaneously;
- restrict the number of tertiary units with rice.

¹ In Training Manual No. 6 (Scheme Irrigation Water Needs and Supply) this is called the operational Scheme Irrigation Need, SIN_{op} .

² In Manual No. 6, this is called the Scheme Water Supply, SWS.

These options need to be discussed with farmers or their representatives, who then select one that they consider acceptable and fair.

Irrigation scheduling

Irrigation scheduling is the activity of making the programme for the coming week (or 10 days, 2 weeks, one month) of the water distribution in the scheme during that period. There are two main reasons for preparing such a programme:

1. The farmers want to know *when* they will receive irrigation water (= timing), *how much* (= flow rate) and *for how long* (= duration).
2. The scheme operators need to know when and how to adjust gate settings.

The irrigation applications are intended to meet the water requirements of the crops cultivated in the scheme.

If just one farm is considered, the irrigation requirement for the next week depends on:

- the crops grown, and the area and growth stage of each crop;
- the moisture conditions in each field;
- the weather conditions expected for the coming week.

The first and second of these items are easy to determine; the area of each crop grown and crop stage. Establishing the moisture conditions in each field with some precision requires specialized equipment, while no one knows for sure what the next week's weather will be. This means that a decision on the next week's irrigation needs cannot be made on the basis of precise knowledge alone; it also requires experience. Farmers are making these types of decisions all the time, because many decisions at the farm must be made without precise knowledge of the future: decisions on what crops to grow, when to plant, how much and when to apply fertilizers and other agro-chemicals are all made on the basis of the farmers' expectations and previous experience with rainfall, sunshine, pests and diseases, crop yields and market-prices.

It is therefore believed that the farmers should first indicate what their irrigation needs are, and that the scheme managers should provide for these needs as best as they can. The procedure for irrigation scheduling depends on the design of the scheme:

- if the scheme is designed to make water deliveries to individual farmers, each of these deliveries needs to be specified in the irrigation schedule;
- if farms in the scheme are grouped into tertiary units which share a common outlet, the scheme operators will only prepare a schedule for water deliveries to the tertiary offtakes.

This section describes irrigation scheduling in the four designs described in the section *Methods for water distribution to tertiary units*.

Scheduling with proportional distribution

With proportional distribution, there is no need for irrigation scheduling: the flow that enters the main canal is distributed evenly over the tertiary units by means of fixed structures. With a gate installed at the entrance of the main canal, the flow into the scheme can be reduced or completely shut off. Such a gate facilitates scheme maintenance and helps to conserve irrigation water in periods of zero or low irrigation demand. Farmers must be consulted and notified of such closures or flow reductions before the start of the irrigation season, so that they can plan their cropping patterns and practices accordingly.

Upstream control with vertical slide gates

This design allows delivery of water to the tertiary units in accordance with the actual irrigation needs of each unit and the water supply available to the scheme. Because of the difficulties involved in setting the gates to the required discharge, it is not recommended to reset the gates more often than once a week. As an example, a procedure is presented for weekly irrigation scheduling for a scheme such as in Figure 14.

The procedure uses a form that each tertiary unit submits weekly to the scheme operators (Figure 17). On the upper part of the form, the farmers make their requests for the coming week, indicating:

- the number of hours per day for which they want to receive irrigation water in their tertiary unit;
- the flow rate that they want to receive at the tertiary offtake.

The scheme operators prepare the irrigation schedule on the basis of these requests. In doing this, they are faced with a number of limitations:

- They will try to avoid resetting the gates within the week. What they can do without too many problems is to close the gate at the entrance of the main canal, without changing the setting of the other gates. This means, however, that all tertiary units will receive irrigation water for the same number of hours each day. As a result, some tertiary units will receive water for a longer or shorter period than they have requested. By adjusting the flow rate, the scheme operators can ensure that the tertiary units receive the volume that they have requested.
- The available water supply may not be sufficient to meet the requested volumes. To prevent this, the scheme operators can impose restrictions on the flow rates and hours of operation. Preferably, these restrictions should be announced *before* the farmers make their weekly requests. In times of constrained water supply, the operators can indicate these restrictions on the request forms simply by crossing out the highest flow rates and/or daily hours of operation on the forms before they are distributed.

FIGURE 17

Form used for weekly scheduling of irrigation deliveries to tertiary units (scheme design: upstream control with vertical slide gates)

REQUEST FORM
(to be filled out by Tertiary Unit representative)

Tertiary Unit No:

Name of Tertiary Unit representative:

Week No.:

No. of hours per day*	Flow rate*
24 hours	60 l/s
18 hours	50 l/s
12 hours	40 l/s
6 hours	30 l/s
	20 l/s
	10 l/s

*) Indicate the requested no. of hours and flow rate with a circle

RESULTING IRRIGATION SCHEDULE
(to be drawn up by scheme operators)

No. of hours per day	Flow rate
24 hours	60 l/s
18 hours; from..... to	50 l/s
12 hours; from.....to	40 l/s
6 hours; fromto	30 l/s
	20 l/s
	10 l/s

FIGURE 18

Example of irrigation scheduling on the basis of request forms (scheme design: upstream control with vertical slide gates)

OVERVIEW OF REQUESTS

TU 1		TU 2		TU3		TU 4		TU5		TU6	
Hrs	Flow	Hrs	Flow	Hrs	Flow	Hrs	Flow	Hrs	Flow	Hrs	Flow
24	80	24	80	24	80	(24)	80	24	80	24	60
18	50	(18)	50	18	50	18	50	(18)	50	18	50
(12)	(40)	12	40	12	40	12	40	12	(40)	12	40
8	30	6	(30)	(6)	30	6	30	6	30	8	30
	20		20		20		(20)		20		(20)
	10		10		10		10		10		10

RESULTING IRRIGATION SCHEDULE

TU 1		TU 2		TU3		TU 4		TU5		TU6	
Hrs	Flow										
24	60	24	60	24	60	24	60	24	(60)	24	60
18	50	18	(50)	18	50	18	50	18	50	18	50
(12)	(40)	(12)	40	(12)	40	(12)	(40)	(12)	40	(12)	40
8	30	6	30	6	(30)	8	30	6	30	8	30
	20		20		20		20		20		20
	10		10		10		10		10		(10)

NOTE: Tertiary Units 2 and 3 will receive more water than requested. This was done to obtain a uniform delivery time of 12 hours per day.

NOTE: The forms can also be used to reflect restrictions that have been agreed upon during irrigation planning. For example, if the water supply is expected to be able to support a rice crop in only three of the six tertiary units, farmers and operators can agree that, in periods of low water availability, only those three tertiary units will be allowed to request the full flow of 60 l/s, while the others may not request more than 30 l/s.

Upstream control with weirs

Irrigation scheduling for this design uses the same principles as the previous one. Due to the duckbill weirs which maintain a nearly constant water level and the discharge distributors that can be set to the required discharge in a single operation, resetting the tertiary offtakes is much easier than in the design with vertical slide gates. This makes it possible for the operators to change the setting more often than once a week. If necessary, they can close the offtakes of some tertiary units while continuing deliveries to others. This means that operators can make irrigation deliveries exactly as requested, provided that there is no shortage of irrigation water. In periods of water shortage, the procedures discussed in the previous section can be applied.

Scheduling with downstream control

With downstream control, there is no need for irrigation scheduling. Farmers can set the discharge from the offtakes according to their requirements. In periods of water shortage, the operators may have to restrict flow rates, timing and duration of water deliveries.

For such periods, the scheme operators could use the forms presented in Figure 17.

Chapter 4

Maintenance

Many irrigation schemes around the world do not provide adequate service to farmers, because gates can no longer move due to rust or because parts are missing or broken, canal sections have collapsed or are full of silt, water level gauges have disappeared, etc. All of the above are the result of poor maintenance.

A newly-built irrigation scheme is expected to function for thirty years or more. Items such as a car or a motorcycle have a much shorter life expectancy, often less than ten years. Yet, in many places where irrigation schemes can be seen which have deteriorated after only a few years of service, cars and motorcycles can also be found that are fifteen or twenty years old and still running.

Therefore a first look is taken at the maintenance of a motorcycle, to see if the same principles can be applied in maintaining an irrigation scheme.

MOTORCYCLE MAINTENANCE

Someone who purchases a new motorcycle receives with it an *instruction booklet*, which usually contains the following sections:

- A description of the motorcycle, showing location of parts.
- Instructions on how to use the motorcycle. How to switch on the ignition, how to operate the gears, etc.
- Regular inspections to be carried out by the driver. Inspection of oil level (daily), tyre pressure (weekly), condition of air filter (monthly), etc.
- Instructions on what the drivers can do themselves to diagnose and remove the cause of failure. Clean sparkplugs and check distance between electrodes if engine does not start, etc.
- Intervals at which motorcycle needs to be serviced. After the first 500 km and every 1 000 km thereafter, etc.
- Technical specifications. Sparkplug gap, contact breaker gap, tyre pressures, lubrication system capacity and recommended lubricants, etc.

The chance of breakdown and need for expensive repairs is much less for a driver who follows the instructions, carries out the regular inspections and presents the motorcycle at an authorized workshop for servicing at the prescribed intervals. All of these activities can be described as *routine maintenance*. Regular inspections and adjustment that reduce the need for repairs may be called *preventive maintenance* (see Box).

ROUTINE (MOTORCYCLE) MAINTENANCE

Periodic routine maintenance is a continuous process that starts right after purchasing the motorcycle. It must be carried out at specified mileage recordings or on a calendar basis if the machine is not used frequently, whichever is the sooner. Maintenance should be regarded as an insurance policy, to help keep the machine in the peak of condition and to ensure long, trouble-free service. It has the additional benefit of giving early warning of any faults that may develop and will act as a safety check, to the advantage of both rider and machine alike.

Even when something is wrong, the alert driver will observe it in time and do something about it before a small problem develops into a big one. This will also help to reduce frequency and cost of repairs.

The workshop should have a manual for each type of motorcycle that they service. This *workshop manual* is produced by the manufacturer of the motorcycle and contains:

- a detailed description of all the components of the motorcycle;
- instructions on the items to be inspected at each interval;
- detailed instructions on how to perform repairs, also indicating the type of tools that need to be used.

The workshop employs one or more technicians who received basic technical training and also some specialized training courses on motorcycle maintenance. Such courses are often organized and even sponsored by the motorcycle manufacturer.

Besides a set of general tools, a well-equipped workshop also has specialized tools for maintenance and repairs of motorcycles.

Cost-conscious owners-drivers will try to do most of the maintenance and repairs themselves. For this purpose, there are *owners' workshop manuals* available for most types of motorcycles. Such a manual is much more detailed than the instruction booklet. It differs from the manufacturers' workshop manual in the sense that the need for specialized tools and equipment is avoided as much as possible.

While good maintenance will make the motorcycle safer to drive, it provides no guarantee against the need for repairs resulting from accidents. These types of repairs may be described as *emergency repairs*.

Maintenance in an irrigation scheme

Maintenance activities for an irrigation scheme fall into three categories:

- Routine maintenance.
- Emergency works.
- Scheme improvement.

These are discussed in the following two sections. The last section deals with management of maintenance activities. In that section the management of irrigation scheme maintenance is also compared with motorcycle maintenance.

Routine maintenance

Routine maintenance activities have to be repeated throughout the lifetime of an irrigation scheme to keep it functioning. Some of these activities are daily routines which do not require special skills:

- greasing of gates;
- removing vegetation from embankments, canals and drains;
- removing silt from canals, drains and structures.

Whenever possible, these daily routines should be done by the water users themselves and otherwise by operational field staff.

NOTE:

In contrast with the motorcycle, much of the maintenance of irrigation schemes consists of very simple operations that can be done by the farmer. This offers a great opportunity for cost reduction when farmers take an active role in undertaking maintenance.

Other routine maintenance activities require skilled artisans, such as a mechanic, a mason, a carpenter and a painter. They may be needed to do routine maintenance work such as:

- repairs to gates and measuring structures;
- repainting of steel structures;
- installation of water level gauges;
- maintenance and small repairs of pumps and engines.

Larger routine maintenance jobs are usually done between irrigation seasons, when the canals are drained. These include:

- major repair or replacement of gates, pumps, and engines;
- large-scale silt clearance from canals and drains;
- large-scale maintenance of roads and embankments.

In the off-season, both farmers and operators are not busy with irrigation and can therefore more easily be engaged in maintenance work. Sometimes, for very large or difficult jobs, it may be necessary to hire a contractor.

Emergency works

Emergency works require immediate and joint action by irrigation staff and farmers, to prevent or reduce the effects of unexpected events such as:

- breach or overtopping of canal embankment or river dike, causing flooding;
- critical failure of pumps or headworks, causing interruption of irrigation water supply;
- natural disasters such as floods, earthquakes or typhoons.

Operational staff must be trained so that they know what to do as soon as they arrive on the scene, such as cutting off the power to a overheated pump, and closing the headworks in case of a canal breach. A good communication system can do much to reduce the damage.

Scheme improvement

The routine maintenance and emergency repairs described above are all aimed at keeping or restoring the technical infrastructure in the condition it was in when it was newly built. There are a number of reasons, however, not just to maintain the scheme *in its original condition*, but to gradually *improve* it. The main reasons are:

- A newly constructed scheme is hardly ever perfect. Some alterations are usually necessary to make it fully operational.
- It is sometimes better to construct a scheme at minimum capacity, with low cost structures. Then, if the scheme proves to be a success, it can be gradually expanded and the structures replaced with more permanent ones.
- Conditions change, both inside and outside the scheme. Improvements are necessary to ensure that the scheme continues to deliver services that correspond with farmers' needs.

Each of these reasons is discussed in more detail below.

Alterations in newly constructed schemes

In the design of an irrigation scheme, many assumptions are made. Examples are:

- The expected seepage and percolation losses for a rice irrigation scheme (see Manual No. 3, Part II, section 4.4 and Manual No. 6, section 3.4.3).
- The expected irrigation efficiency (see Manual No. 4, Annex 1, and also Manual No. 6, Chapters 3 and 4).
- The expected roughness of the canal bed and sides (see Manual No. 7, section 3.3.2).
- The bearing capacity of the soil (see Manual No. 8, section 7.1).

Even with extensive field research in the area at the planning stage, it is not possible to be absolutely accurate in predicting these values. If actual seepage and percolation losses in a particular section of a rice scheme are much higher than was assumed, the capacity of the canals and/or turnouts serving this area may have to be increased, following procedures

explained in Manual No. 7, Annex 1. An underestimate of canal roughness may be corrected through either enlarging the cross-section, or by canal lining (see Manual No. 7, Chapter 6). Similar actions may be needed if estimates of irrigation efficiencies were too optimistic. Overestimating the bearing capacity of a soil may result in collapse or sinking of structures, which then have to be replaced or adjusted to the original design level.

Gradual scheme development and improvement

"When a scheme is first built under pioneer conditions it is usually most economical to build many of the structures of wood, as at that time there are many unknown conditions and freight rates on cement and iron are usually high. Later on, the wooden structures may be replaced with more permanent steel or concrete structures. In the same way, the canal system as originally built may be constructed of minimum capacity, with the idea of enlarging it as the demands for water increase. It is frequently not economical to build a full sized canal at first when it only carries a reduced supply in the first few years. Due to the small demand, the full sized canal would fill up rapidly with sediment, whereas due to the higher flow velocity in a smaller canal it can be more easily kept clean." (Copied with minor alterations from: Newell, F.H. *Irrigation Management*. Appleton, New York. 1916)

Enlarging the capacity of an existing canal is discussed in Annex 1 of Manual No. 7, Canals). Another improvement is canal lining (see Manual No. 7, Chapter 6).

Adapting to change

A design that is well adapted to farmers' needs at the time of construction can become inadequate due to changes that occur both inside and outside the scheme. A few examples are given below:

- A change in prices for agricultural crops can result in a different cropping pattern.
- Job opportunities outside agriculture may reduce the availability of farm labour.
- A change in lifestyle may result in farmers no longer wanting to irrigate during the night.
- Increased demand for water for domestic and industrial purposes can reduce the volume available for irrigation.

In order to cope with these changing conditions, it may be necessary to change the water distribution practices in the scheme. For example, a scheme that was originally designed for rice cultivation, on the basis of proportional water distribution to the tertiary units during 24 hours a day, is no longer adequate when farmers prefer to grow vegetables and only want to irrigate during the daytime. In such a case, the scheme's infrastructure may need to be upgraded to enable a more appropriate method of water distribution, such as discussed in Chapter 3 of this Manual.

Management of maintenance activities

The objectives of maintenance management in an irrigation scheme are:

- to keep the scheme in good operating condition so that it will provide uninterrupted service;
- to extend the useful life of the scheme;
- to achieve the above at the lowest possible cost.

The same objectives apply to motorcycle maintenance. In order to keep the costs down, both in irrigation and in motorcycle maintenance, an attempt should be made to reduce the need for costly repairs.

A motorcycle may end up in the workshop for repair after:

1. Routine inspection by owner.
2. Regular service interval inspection by workshop.
3. Breakdown.
4. Emergency (accident).

Likewise, the need for repair by the irrigation maintenance unit may be the result of:

1. Routine inspection by operator.
2. Periodic inspection by maintenance unit.
3. Breakdown.
4. Emergency (flood, pump failure).

Items 1 and 2 are *preventive maintenance* activities. Routine inspections represent an effort on the part of the motorcycle owner and a cost for the management of an irrigation scheme. Repairs resulting from such inspections represent an effort for the owner of the motorcycle when he/she does the repair himself/herself, and a cost when the repair is done by the workshop or when it involves purchase of replacement parts and materials.

For the irrigation scheme, a repair that is identified by an operator and can be performed by the same operator is the least costly; expenditures are just the cost of the operator and perhaps some materials. If the repair needs to be done by the maintenance unit, it usually implies higher costs and an organizational effort.

It is the organizational effort that marks the difference between maintenance of a motorcycle and that of an irrigation scheme. Another difference is that the relationship between the owner/driver of the motorcycle and the workshop is very clear, while no such clear relationship exists in maintenance of an irrigation scheme. The basic principle that applies to motorcycles and irrigation schemes alike is that:

While preventive maintenance represents efforts and costs, it costs much less than repair of breakdowns.

Planning maintenance

Planning maintenance activities means deciding *what* activities should be done, *who* should do them, and *when*. The schedule for maintenance of a motorcycle is prepared by the

manufacturer. It involves only two parties, who both have received such a schedule from the manufacturer:

- The owner of the motorcycle, who has received the *instruction booklet*, which specifies activities by the owner.
- The workshop that is authorized by the manufacturers to service their product, which has a *workshop manual* which specifies what should be done at each service interval.

The instruction booklet and workshop manual are prepared for a specific model. They therefore apply to thousands of identical motorcycles. Irrigation schemes are hardly ever identical. This means that the equivalent of the instruction booklet and workshop manual - *the preventive maintenance programme* - has to be developed for each individual scheme.

The activities performed under the preventive maintenance programme can be planned in advance, indicating for each task when it should be done and by whom.

Inspections for identification of maintenance needs can also be scheduled in advance, indicating when inspections will take place and by whom. Of course, it is not possible to predict which maintenance needs will be identified through these inspections. A practical solution is to have an annual inspection as a basis for drawing up the maintenance programme for the next year.

The maintenance needs identified at this annual inspection will not all have the same degree of urgency. For example, erosion of the embankment of a storage dam must have top priority and be corrected without delay, because failure of the dam would have serious consequences. Other activities, such as silt or vegetation removal from a canal, may safely be planned a few months later. The main factors to consider when setting priorities are the consequences of not doing the maintenance work, in terms of:

- safety; risk to human life and risk of structural failure;
- effect on crop production due to interruption of water deliveries.

The maintenance needs identified will then be scheduled into the maintenance plan according to their priority, together with the preventive maintenance activities.

Service agreement for maintenance

In the case of motorcycle maintenance, there are only two parties involved: the owner and the workshop. It is up to the owner to decide whether to bring his/her motorcycle to the workshop for servicing or repair, or to perform maintenance tasks himself/herself, or to forget about maintenance altogether. In the latter case, the owner risks all of the following:

- malfunctioning and breakdown of the motorcycle;
- the police seizing the motorcycle because it is unsafe to drive;
- an accident.

The owner also knows he/she will be presented with a bill every time the motorcycle is taken to the repair shop. If the owner is not satisfied with the service provided by the workshop, he/she may decide to go to another workshop.

In an irrigation scheme, the situation is often less clear, especially when the scheme is owned by the government and the staff of the maintenance unit are government employees. A service agreement between the farmers and the maintenance unit will help to clarify responsibilities.

A service agreement for maintenance must specify:

1. The two parties who are making the agreement.
2. The purpose of the agreement.
3. A description and timing of planned maintenance activities.
4. A specification of items for which repair services will be provided, procedures for requesting repair services and maximum time period within which repair services will be provided.
5. The method for calculating costs of services.
6. The timing of bills for services, the time period within which bills must be paid and the surcharge applicable for bills in arrears.
7. The compensation payable if the services specified in the agreement are not provided.
8. The authority that will arbitrate in the case of disputes.

Chapter 5

Financial control

Developing and managing an irrigation scheme requires money. This chapter discusses investment and operational costs, the limited potential of farmers to repay investment costs, the need to recover operational costs from farmers, various methods for charging users, and the principle of financial autonomy.

TYPES OF IRRIGATION COSTS

There are two main types of irrigation costs: investment costs and operation and maintenance costs.

Investment costs

Investment costs are all the expenditures needed for making a new scheme. These are not only the costs of construction materials (cement, steel) and equipment (pumps, gates) but also the salaries and wages of those involved in the design and construction of the scheme and the operational costs of all the machinery used during construction. Investment costs for a new scheme are usually much higher than the amount of money the farmers of that scheme can contribute.

Example of investment costs:

A scheme of 100 ha has been developed for a group of 200 farming families. The average farm size is 0.5 ha. The investment cost was \$US 200 000. This corresponds to:

- an investment cost of \$US 1 000 per family, or
- an investment cost of \$US 2 000 per ha.

An investment cost of \$ 1 000 per family is high compared to the increase in family income due to irrigation, for which two examples are given below. In the first example, the additional income from irrigated rice production amounts to \$ 150. A rice producing family will find it difficult to repay the \$ 1 000 investment cost: it would absorb all of the additional income from six harvests.

Example of income from rice production:

	Without irrigation	With irrigation
Production per ha	2.5 tons	5.0 tons
Market value per ton	\$US 200	\$US 200
Production cost per ton	\$US 80	\$US 80
Income per ha	\$US 300	\$US 600
Income per family (farm-size 0.5 ha)	\$US 150	\$US 300
Increase in family income due to irrigation	0	\$US 150

With horticultural production, however, the increase in income could be substantially higher, as is demonstrated in the next example.

Example of income from tomato production:

	Without irrigation	With irrigation
Production per ha	20 tons	40 tons
Market value per ton	\$US 120	\$US 120
Production cost per ton	\$US 50	\$US 50
Income per ha	\$US 1 400	\$US 2 800
Income per family (farm-size 0.5 ha)	\$US 700	\$US 1 400
Increase in family income due to irrigation	0	\$US 700

In the above example, the additional income from two crops of tomatoes would be sufficient to repay the investment.

These examples demonstrate that the ability of farmers to repay the investment costs of their irrigation scheme depends very much on the type of crops that they are able to produce and sell.

Operational costs

Operational costs are the expenditures for operating, maintaining and managing the scheme. These expenditures come back year after year, for as long as the scheme is kept in operation. Therefore, they are also called *recurrent costs*. An important principle is that operational

costs of an irrigation scheme should be paid by the users. If users are not capable or willing to pay the operational costs, this is an indication that something is wrong. For example:

- recurrent costs are too high, or
- additional income from irrigated agriculture is too low, or
- farmers believe they can get away with not paying.

The causes and cures for each of these situations are discussed below.

Problem 1: Recurrent costs are too high.

Possible causes/cures:

- Poor design leading to high cost of water distribution/improve design (Chapter 3) and more farmers' involvement in operation, better accountability of designers to farmers.
- Poor design leading to high maintenance costs/improve design, more farmers' involvement in maintenance, better accountability.
- Too many operational staff/reduce agency staff, more farmers' involvement and better accountability.

Problem 2: Additional income from irrigation is too low.

Possible causes/cures:

- Irrigation services not adequate/improve design, management.
- Other farm inputs not adequate (agrochemicals, extension, marketing)/mainly outside control of irrigation scheme managers.

Problem 3: Farmers believe they can get away with not paying.

Main cause/cure:

- Design and implementation of physical infrastructure before farmers' organization capable of assuming financial responsibility was in place/do not start construction before agreement with farmers' organization on how recurrent costs will be paid by the users.

METHODS OF CHARGING USERS

There are various methods for charging users:

- by the irrigation volume;
- by the size of the irrigated area;
- by a share of the harvested crop.

In some countries, the state recovers irrigation costs through taxes:

- by a tax on irrigated land;
- by a sales tax on crops that are usually produced with irrigation;
- by personal income tax.

Imposing and collecting these taxes are responsibilities of the state and not of the irrigation scheme managers or the farmers organization. Only the first three methods are discussed.

Charging by irrigation volume

The advantage of this method is that it encourages efficient water use. It requires measuring and recording of volumes delivered at each outlet. This is relatively easy if water is delivered from pressurized pipes. Outlets from such pipes can be provided with a meter that records the total delivered volume. One reading per year is sufficient to determine the volume delivered in the last year.

Recording delivered volumes from outlets in open canal schemes is more complicated. The structures described in Chapter 5 (Flow measurement) of Manual No. 8 (Structures for water control and distribution) allow the determination of the discharge, Q , at a particular moment. In order to calculate the delivered volume, V , the discharge and the length of delivery time need to be recorded:

$$V_{\text{delivered}} = Q \times t$$

with: $V_{\text{delivered}}$ Delivered volume (m^3)
 Q Discharge (m^3/s)
 t Length of delivery time (s)

If the outlet can be set at different discharges, the total delivered volume in one year or one irrigation season can be calculated, provided that at each application (1, 2, 3 ... n) the discharge (Q) and length of application (t) were recorded:

$$V_{\text{total}} = (Q_1 \times t_1) + (Q_2 \times t_2) + (Q_3 \times t_3) + \dots + (Q_n \times t_n)$$

These recordings of delivered volumes correspond to the type of irrigation scheduling that was discussed in Chapter 3. They involve some administration, but the procedure and calculations are fairly simple.

If the discharge changes considerably during the application, a reliable estimate of the delivered volume requires measurement of Q at regular intervals throughout the application

period. While this procedure may be used for research purposes, it is not a practical base for charging users simply because the cost of collecting the information is too high.

Charging by the size of the irrigated area

A fixed amount is paid per hectare of irrigated land. There are various possibilities in applying this method:

- a. A yearly charge for every hectare of land within the irrigation scheme.
- b. A yearly or seasonal charge for every hectare of irrigated land.
- c. A seasonal charge for every hectare of irrigated land, depending on the type of crop cultivated.

The only record needed with method (a) is the size of each farm within the scheme. The charge for a particular farm is the same each year, unless the unit rate is changed. The second method requires measurement of the irrigated area on each farm. Method (c) involves recording irrigated area and crop type on each farm. Charges for crops with high irrigation requirements, such as rice and sugar cane, are higher than for the other irrigated crops.

The effort involved in taking records, even when using method (c), is much less than with the method of charging by the irrigation volume. This is the reason that the method of charging by the size of the irrigated area is more common than charging by the volume. The main disadvantage is that it does not encourage farmers to use water efficiently.

Charging by a portion of the harvested crop

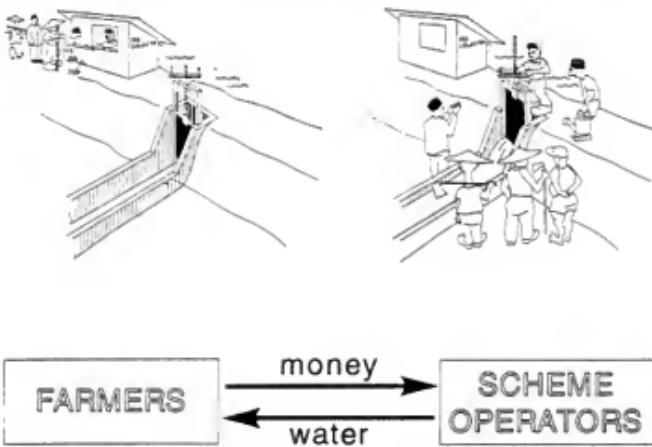
Instead of paying in cash, the farmer makes available a portion of his/her harvested crop. This amount is either a fixed weight per hectare, or a percentage of the harvest. The advantage of a fixed weight is easy administration and a steady source of funds for the irrigation scheme managers. The advantage for farmers of using a percentage is that they pay less when the harvest is poor and more with a good harvest. The disadvantage is the need to determine the size of the harvest at every farm.

FINANCIAL AUTONOMY

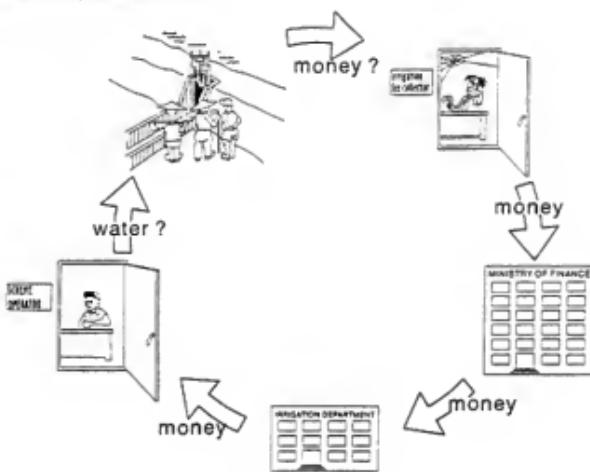
Worldwide experience shows that schemes perform better when the services provided by the scheme are financed from the service fees collected from the farmers in that scheme (Figures 19 and 20).

FIGURE 19

A financially autonomous scheme: recurrent costs are directly recovered from the users

**FIGURE 20**

A government-dependent scheme



Annex 1

Irrigation Service Agreement

IRRIGATION SERVICE AGREEMENT

Between the Water Users' Association (WUA) and the Scheme Operators (SO) of the Irrigation Scheme, who have agreed upon the following articles.

Article 1. Services

- The SO provides irrigation services to the Tertiary Units (TU) of the scheme, on the basis of requests received from the representative of each TU.

Article 2. Procedures for Request and Delivery of Services

- The TU representative fills out and submits on or before each Wednesday a standard request form, indicating (a) No. of hours per day and (b) Flow rate required in the following week.¹
- In drawing up the delivery schedule, the SO can change the requested values, with the specified limits²:
 - No. of hours per day (T): $T_{scheduled} = T_{requested} \pm 6$ hours
 - Flow rate (Q): $Q_{scheduled} = Q_{requested} \pm 20$ l/s
 - Volume (V)³: $V_{scheduled} >/- V_{requested}$

Article 3. Procedures for Monitoring Service Level

- Flow rates are measured with a flume installed at the head of each TU. These flumes are equipped with a gauge that indicates the water level required for a discharge of 10, 20, 30, 40, 50 and 60 l/s.
- If the difference between the scheduled and the observed flow rate is more than 5 l/s for a continuous period of more than 2 hours, this is reported to the SO by the TU representative. The SO will correct the situation within two working days and will compensate the resulting $V_{requested} - V_{delivered}$ within five working days at no additional charge.

Article 4. Services in Times of Water Shortage

- In times of water shortage, the SO may impose restrictions on the flow rates or irrigation durations, or both. The SO will announce these restrictions by crossing out the higher flow rate(s) and/or duration(s) on a request form that will be displayed outside the SO's office.

.....

Article 5. Service Fees

- o Service fees are charged to each TU on the basis of the total of the irrigation volume requested. The service fee will be announced before each irrigation season.

Article 6. Billing

- o Bills are sent to the representative of each TU in December and July. Payments must be received within one month.

Article 7. Consequences of Delayed Payment

- o A TU that has not paid within the specified period will not receive irrigation water until payment plus 1.5 percent interest per month on bills in arrears has been received.

Article 8. Duration of the Agreement

- o This Agreement is entered into for the duration of one year, and renewable from year to year by mutual consent. Changes in any of the Articles of this Agreement may be proposed by either party at any time and will become effective immediately after achieving mutual consent.

Article 9. Disputes

- o Disputes that may arise from non-compliance with this Agreement will be submitted for arbitration to the Provincial Director of the Ministry of Agriculture.

¹ An example of such a standard form is given in Figure 17 (form used for weekly scheduling of irrigation deliveries).

² An example of a change in T and Q is given in Figure 18 (example of irrigation scheduling on the basis of request forms).

$$\begin{array}{lll} \text{For TU2: } & T_{\text{scheduled}} & = 12 \text{ hours} \\ & Q_{\text{scheduled}} & = 50 \text{ l/s} \end{array} \quad \begin{array}{lll} & = T_{\text{requested}} & - 6 \text{ hours} \\ & = Q_{\text{requested}} & - 20 \text{ l/s} \end{array}$$

The resulting $V_{\text{scheduled}}$ ($12 \text{ hours} * 3600 \text{ seconds} * 50 \text{ l/s} = 2 160 000 \text{ litres, or } 2160 \text{ m}^3$) is more than $V_{\text{requested}}$ ($18 \text{ hours} * 3600 \text{ seconds} * 30 \text{ l/s} = 1 944 000 \text{ litres, or } 1944 \text{ m}^3$).

³ Note that Article 4 specifies that TU will be charged on the basis of $V_{\text{requested}}$, not $V_{\text{scheduled}}$.

IRRIGATION WATER MANAGEMENT TRAINING MANUALS

1. Introduction to irrigation, 1985 (A E F S)
2. Elements of topographic surveying, 1985 (E F S)
3. Irrigation water needs, 1986 (A E F S)
4. Irrigation scheduling, 1989 (E F S)
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6. Scheme irrigation water needs and supply, 1992 (A E F S)
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The Irrigation Water Management Training Manuals are available through the authorized FAO Sales Agents or directly from Distribution and Sales Section, FAO, Viale delle Terme di Caracalla, 00100 Rome, Italy.

Irrigation scheme operation and maintenance is the tenth in the series of training manuals on irrigation prepared jointly with the International Institute for Land Reclamation and Improvement (ILRI). The manual presents some of the difficulties confronting irrigation organizations in undertaking their duties and provides some suggestions for resolving them. The paper then discusses the methods of operating an irrigation network and the working principles involved. Maintenance tasks are discussed using the maintenance of a motorcycle as a reference for the corresponding activities in an irrigation scheme. Finally, reference is made to the need for having an effective financial control whereby the management of the system has enough resources to undertake the operation and maintenance tasks. The manual is addressed to small- and medium-scale schemes and assumes that the management organization is already in place.

ISBN 92-5-103676-7 ISSN 1020-4261



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W2599E/1/10 96/1700

M-56